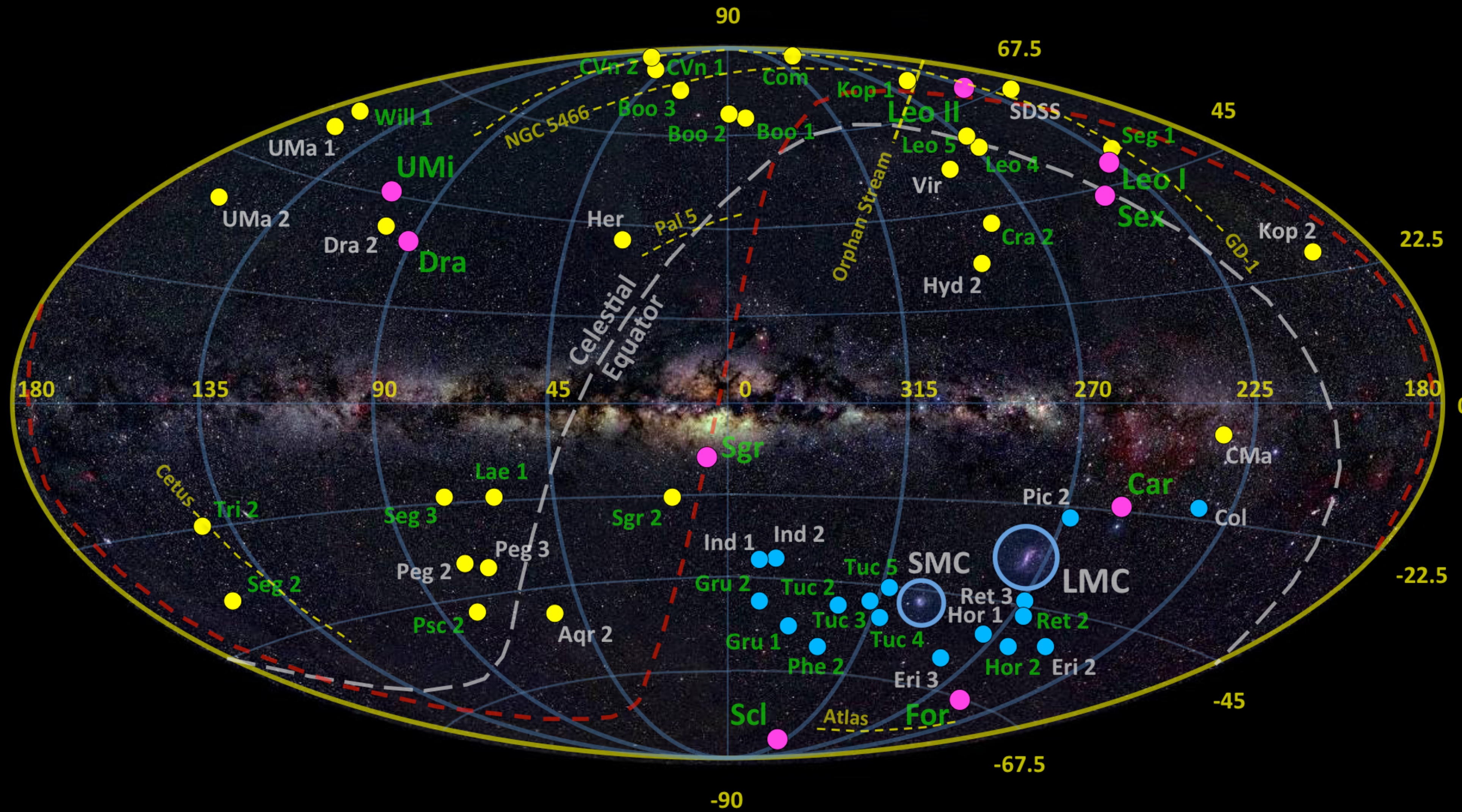
# The environment of the r-process





## Ian U. Roederer (U. Michigan and JINA-CEE)



Generous funding for my work has been provided by:

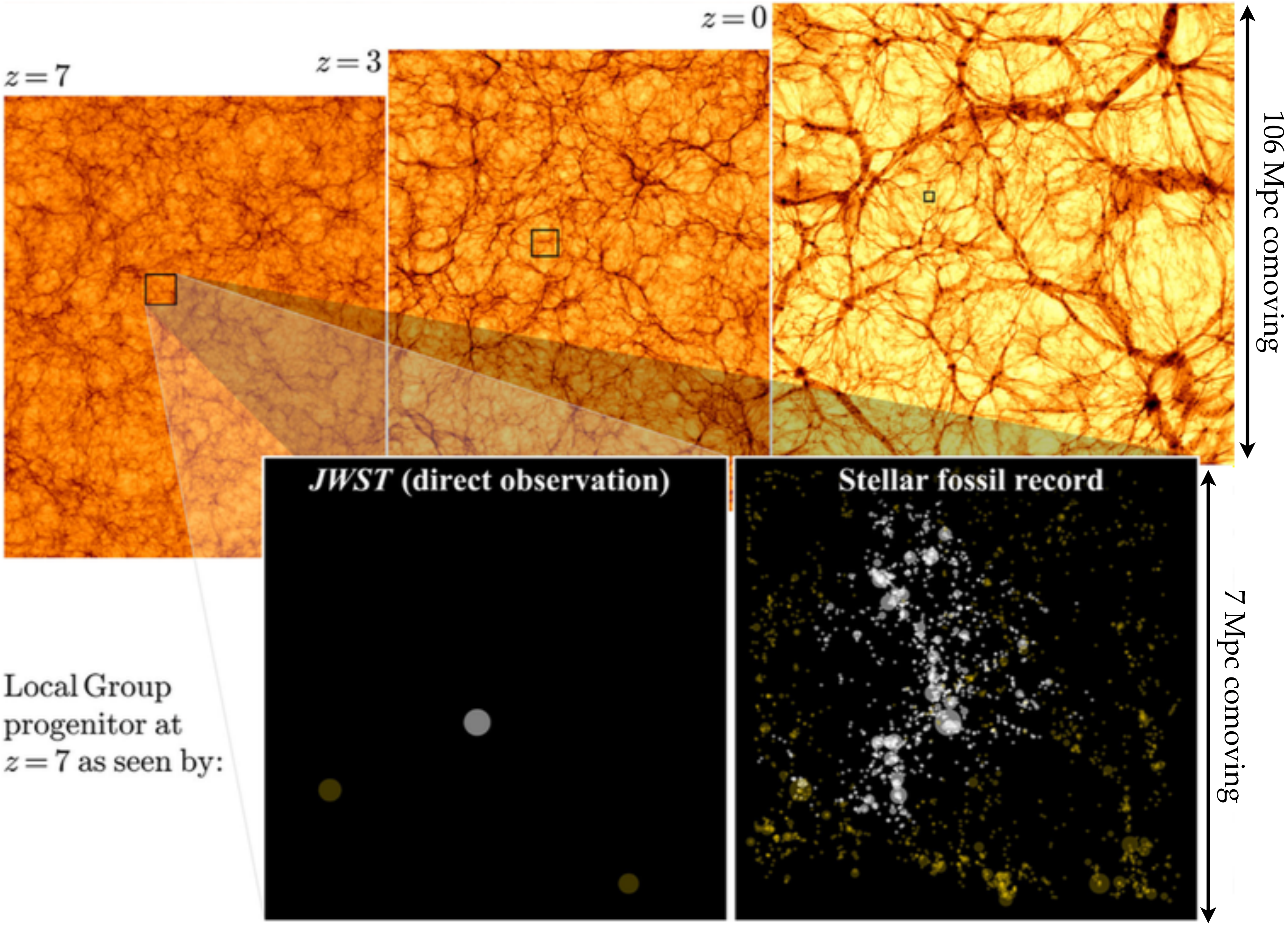
NSF National Science Foundation
WHERE DISCOVERIES BEGIN

NASA


image: A. Mellinger (Central Michigan U.), M. Mateo (U. Michigan)

How representative, cosmologically speaking, is the Local Group?

Boylan-Kochin et al., Mon. Not. Roy. Astron. Soc., 462, L51 (2016)

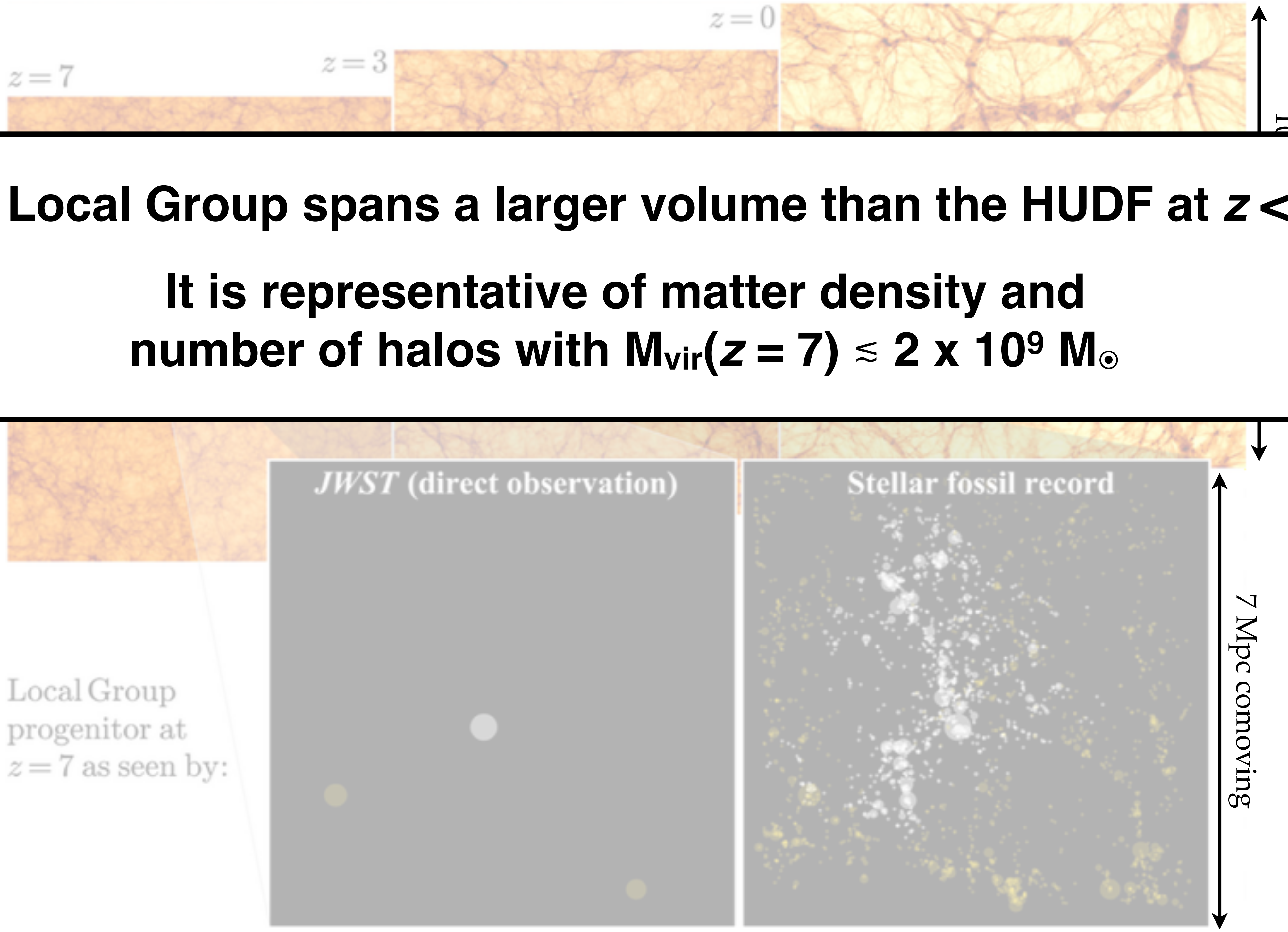



JWST = James Webb Space Telescope

Boylan-Kochin et al., Mon. Not. Roy. Astron. Soc., 462, L51 (2016)
slices from the *Illustris* simulation

**The Local Group spans a larger volume than the HUDF at $z < 3$.**

**It is representative of matter density and number of halos with $M_{vir}(z = 7) \lesssim 2 \times 10^9\ M_\odot$**

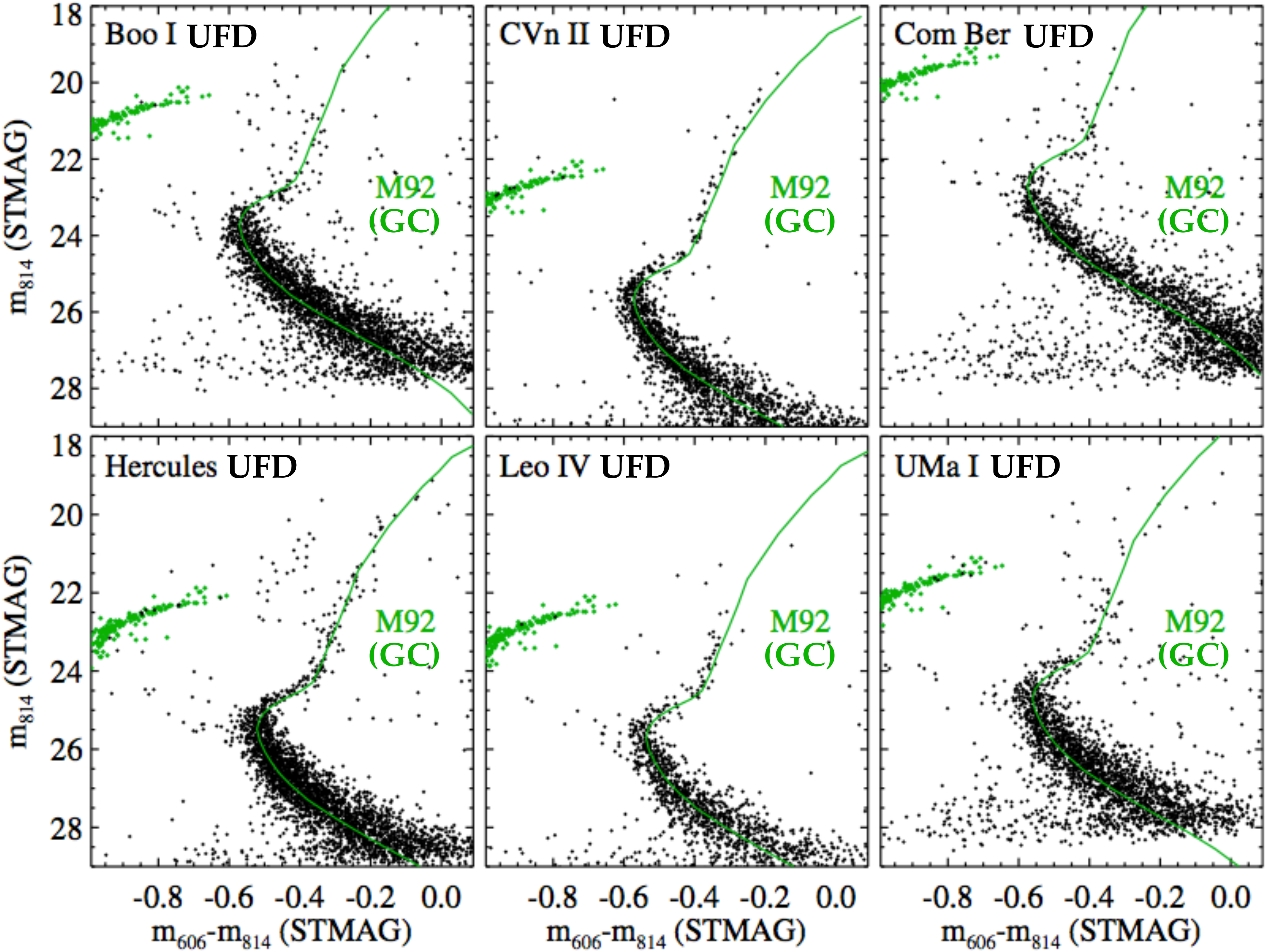



JWST = James Webb Space Telescope

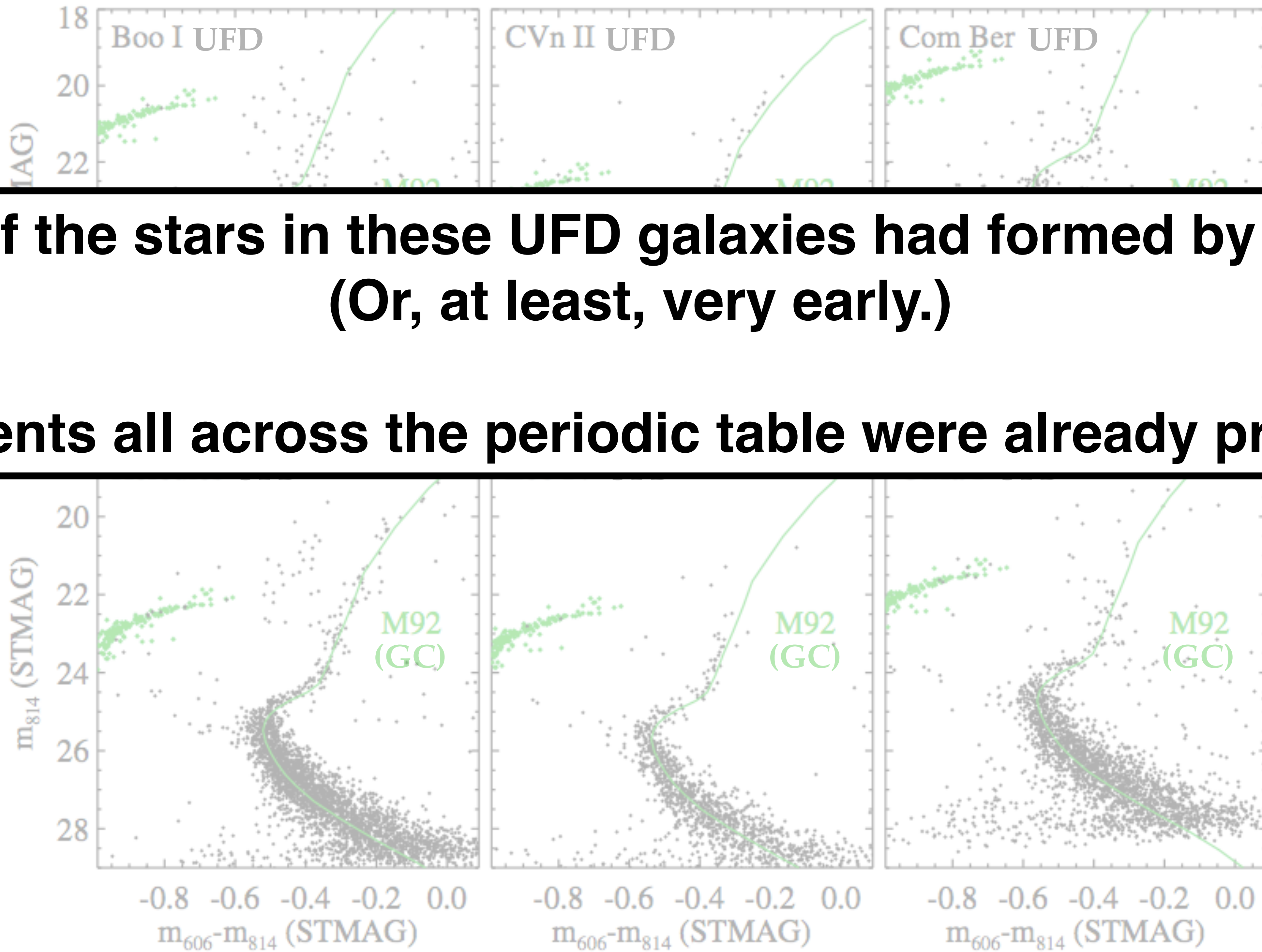
Boylan-Kochin et al., Mon. Not. Roy. Astron. Soc., 462, L51 (2016)
slices from the *Illustris* simulation

## ultra-faint dwarf (UFD) galaxies

* have low luminosity ($M_V > -7$ or so)
* are dark-matter dominated
* contain old, metal-poor stellar populations
* contain metals




Brown et al., Astrophys. J., 796, 91 (2014)

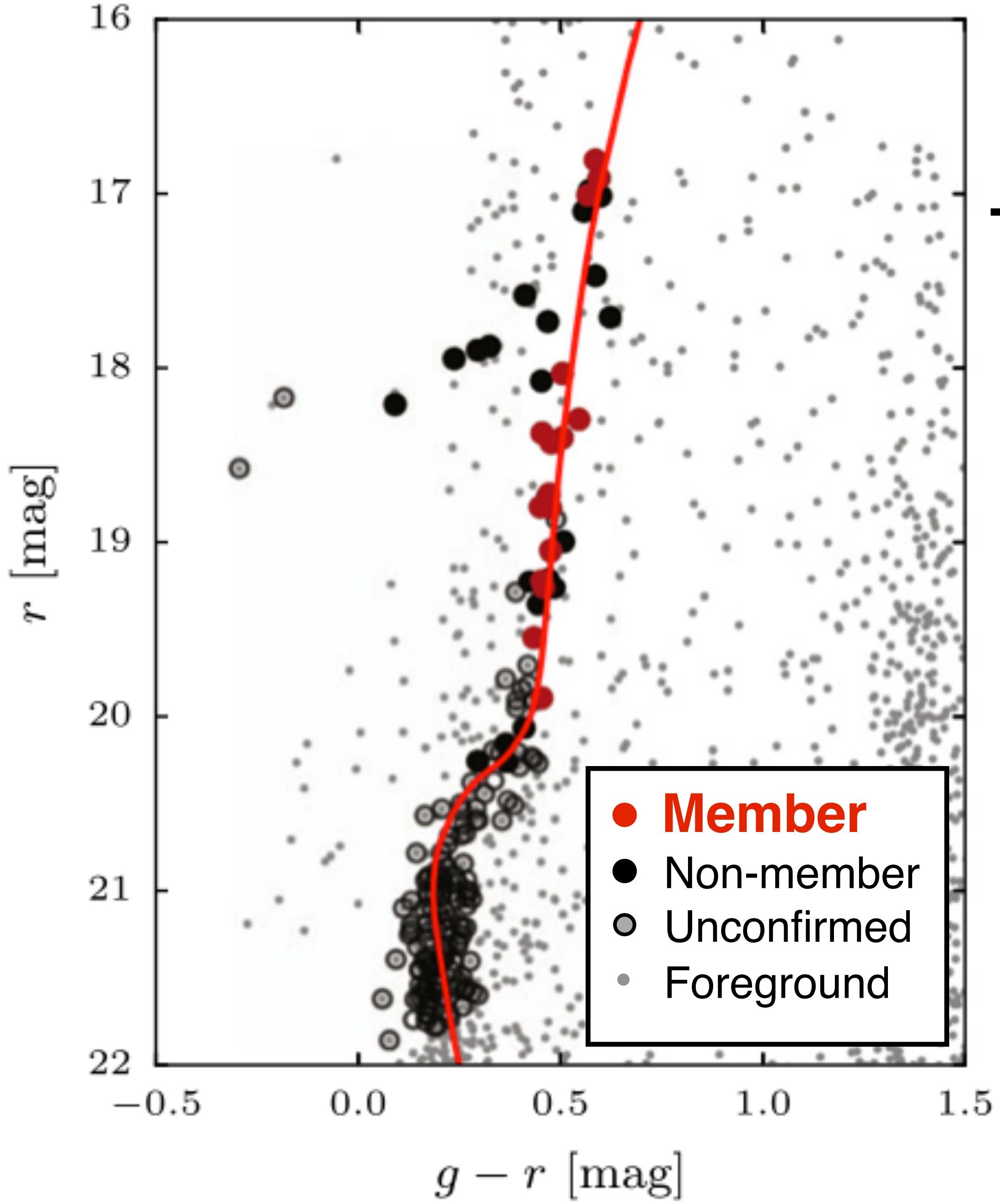



**75% of the stars in these UFD galaxies had formed by z ~ 10.**
**(Or, at least, very early.)**

**Elements all across the periodic table were already present.**

Brown et al., Astrophys. J., 796, 91 (2014)

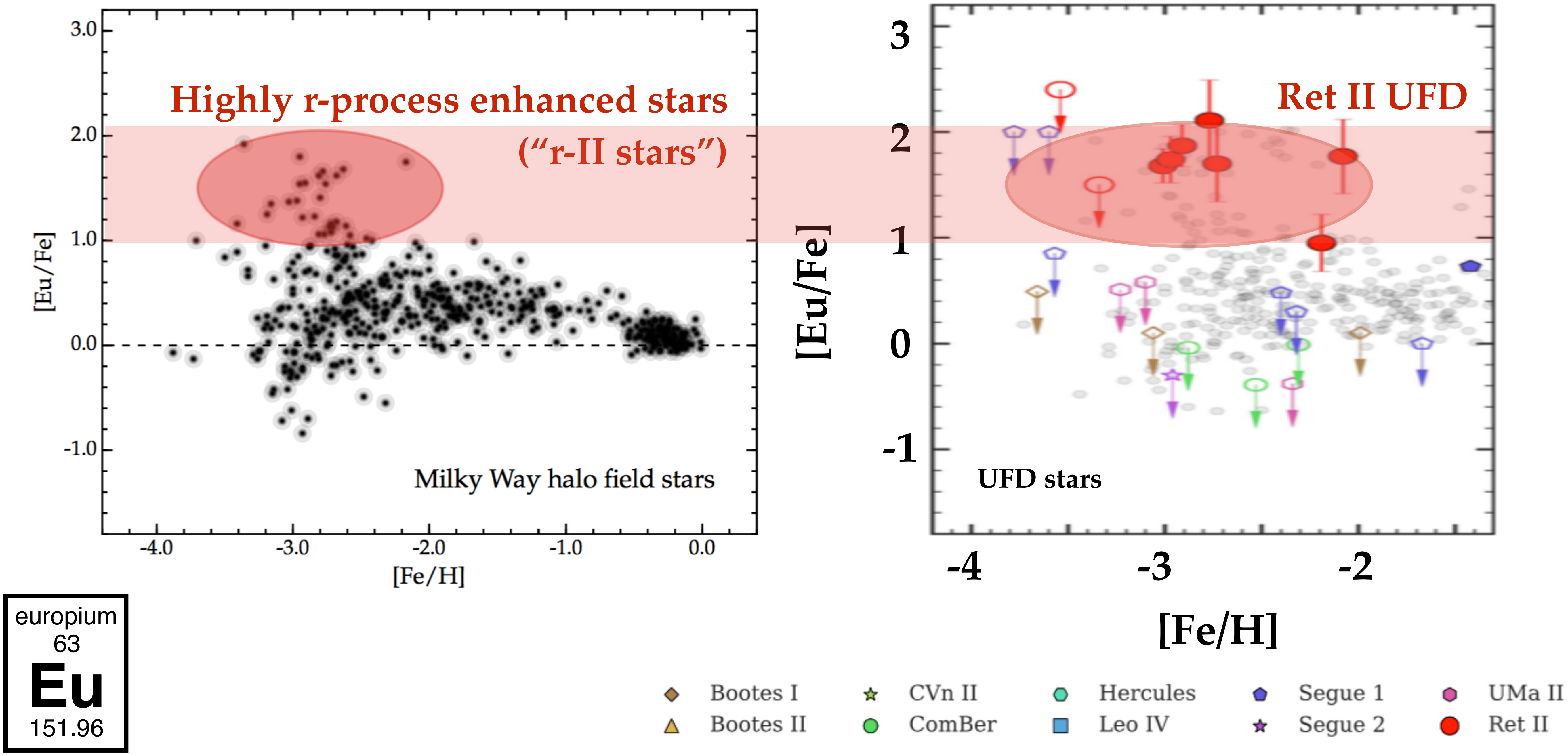
# Reticulum II




| Basic properties of Ret II UFD galaxy | |
|---|---|
| distance | 30 kpc |
| stellar mass | 2600 $M_\odot$ |
| absolute mag. ($M_V$) | –2.7 |
| mass-to-light ratio | 500 |
| mean [Fe/H] | –2.6 |
| [Fe/H] dispersion | 0.5 |


Koposov et al., Astrophys. J. 805, 130 (2015)
Bechtol et al., Astrophys. J. 807, 50 (2015)
Walker et al., Astrophys. J. 808, 108 (2015)

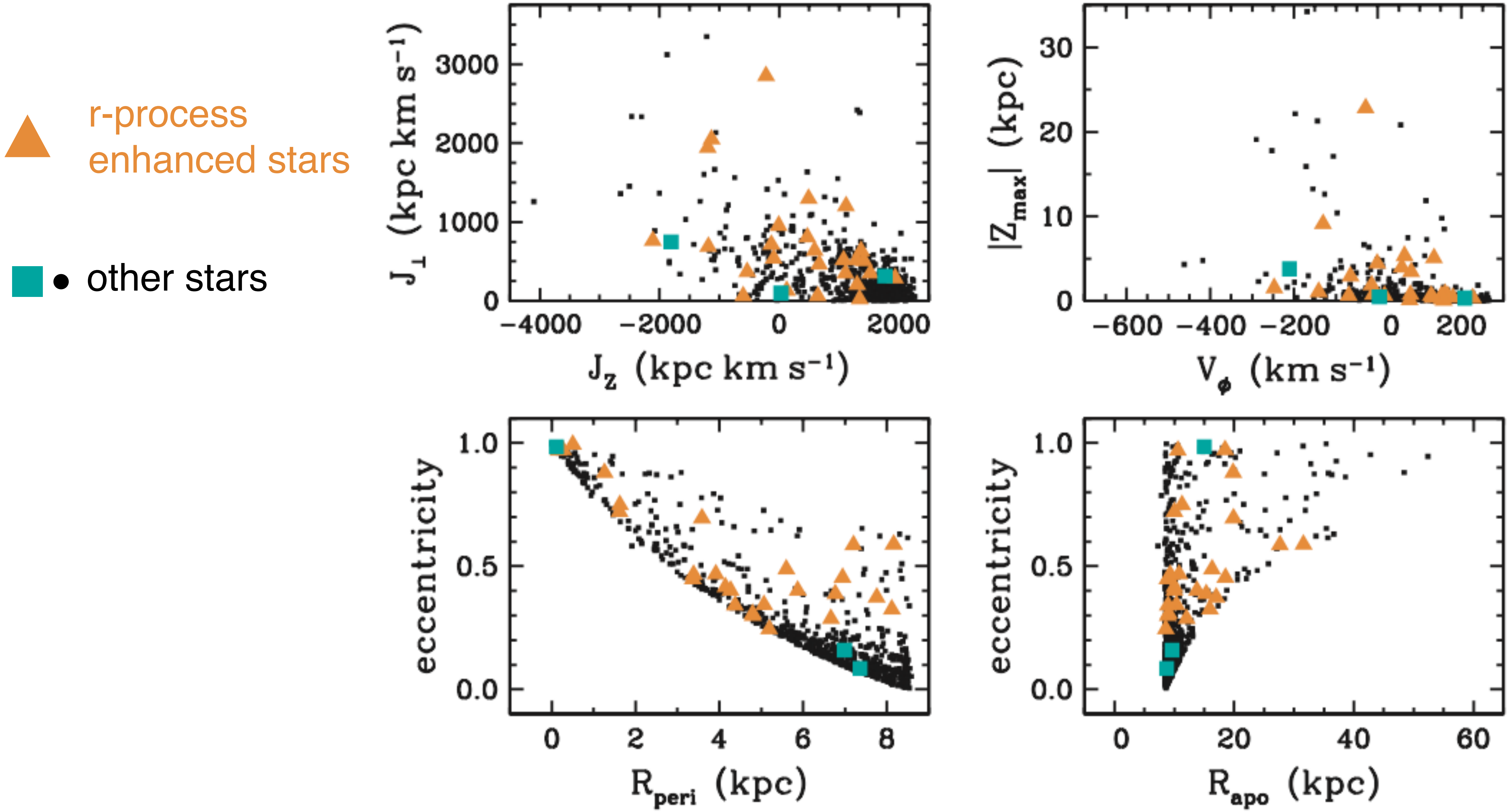
# The heavy element enhancement in Ret II matches the r-II stars in the halo.



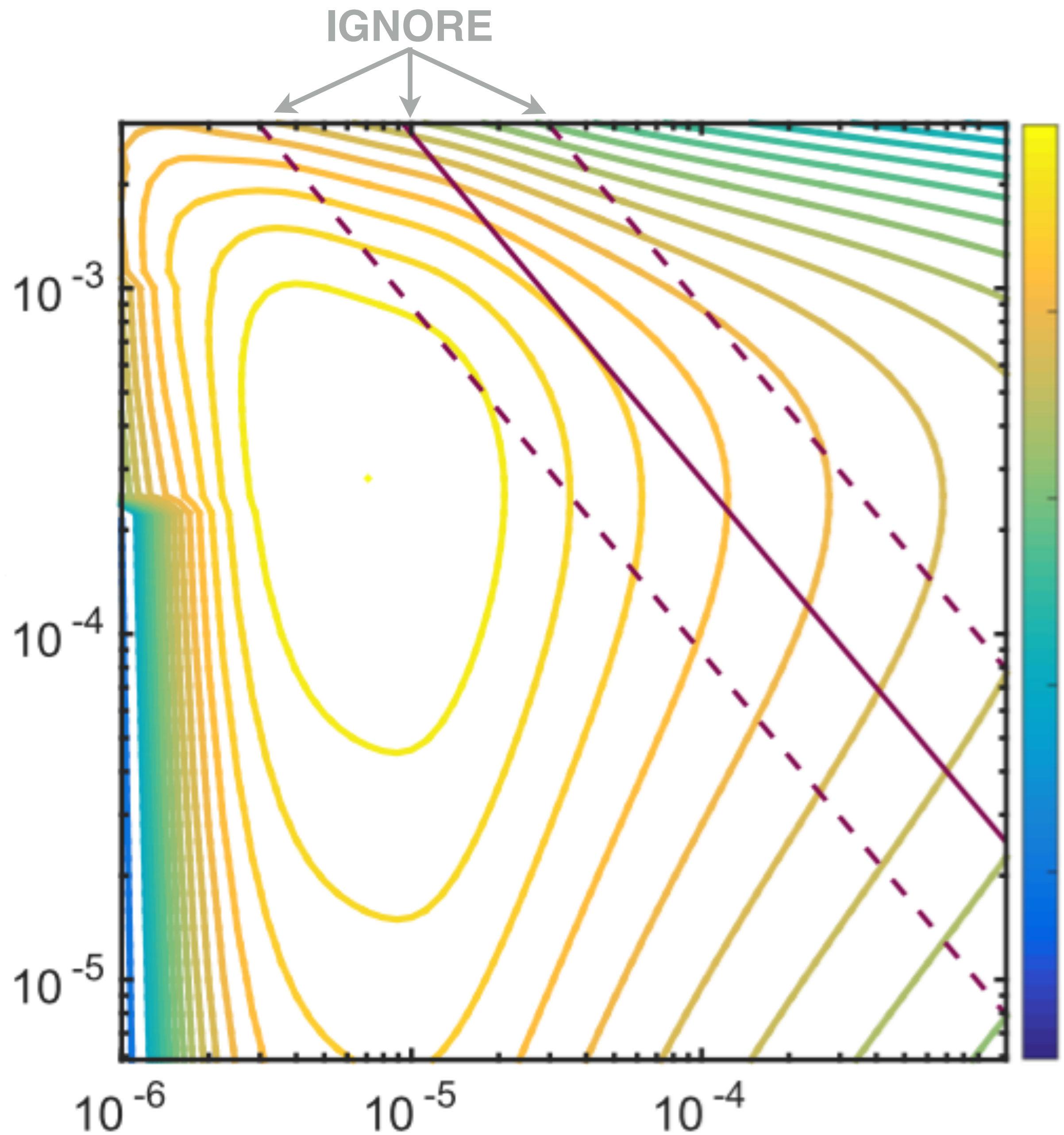

IUR, unpublished

Ji et al., Astrophys. J., 830, 93 (2016) [rescaled]

see also Roederer et al., Astron. J, 151, 82 (2016)

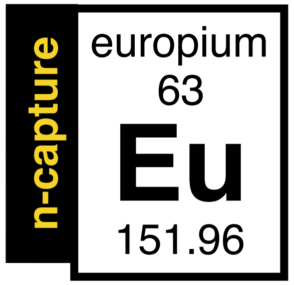



Roederer, Astron. J., 137, 232 (2009)

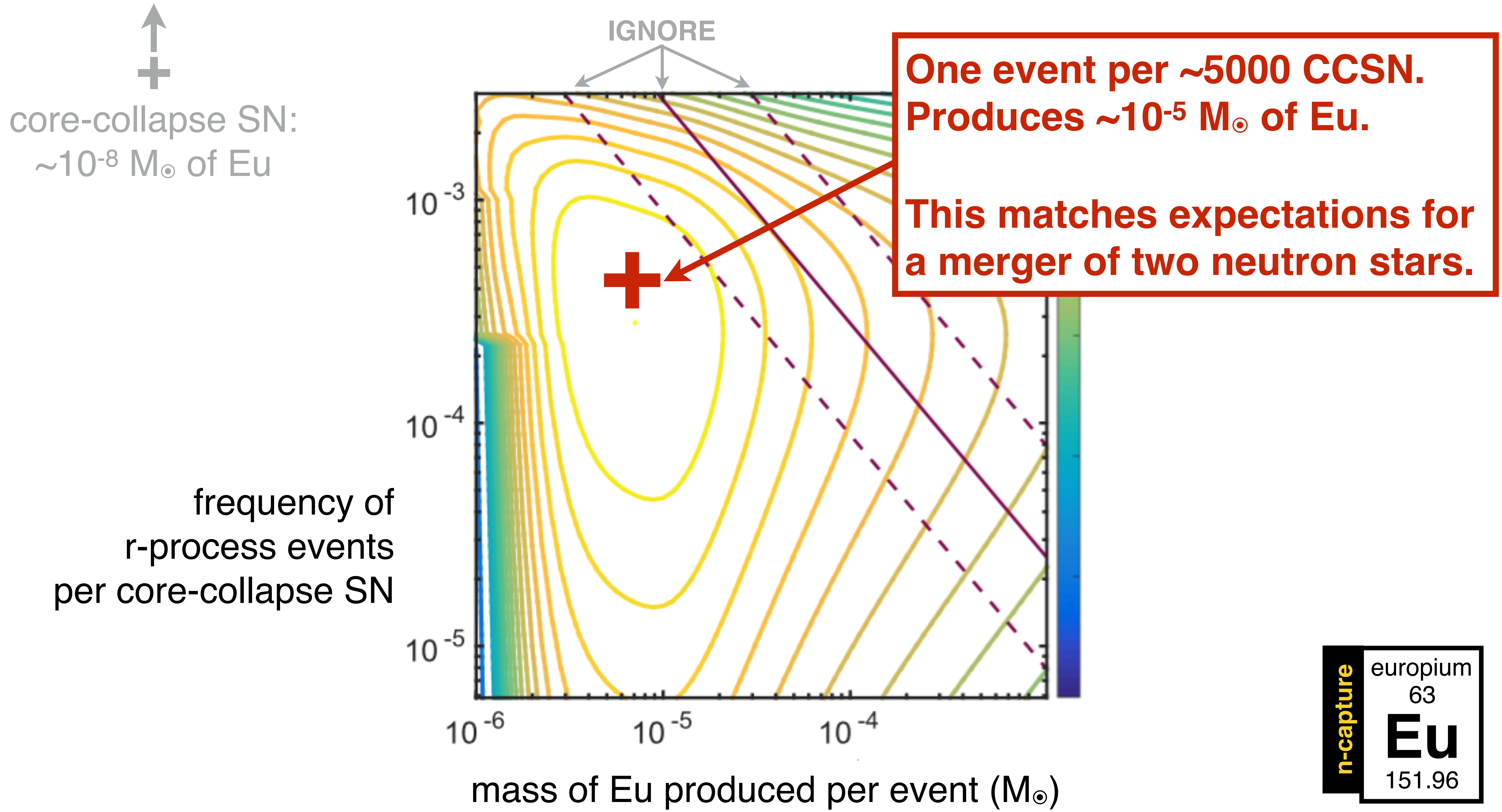



frequency of
r-process events
per core-collapse SN

mass of Eu produced per event ($M_\odot$)

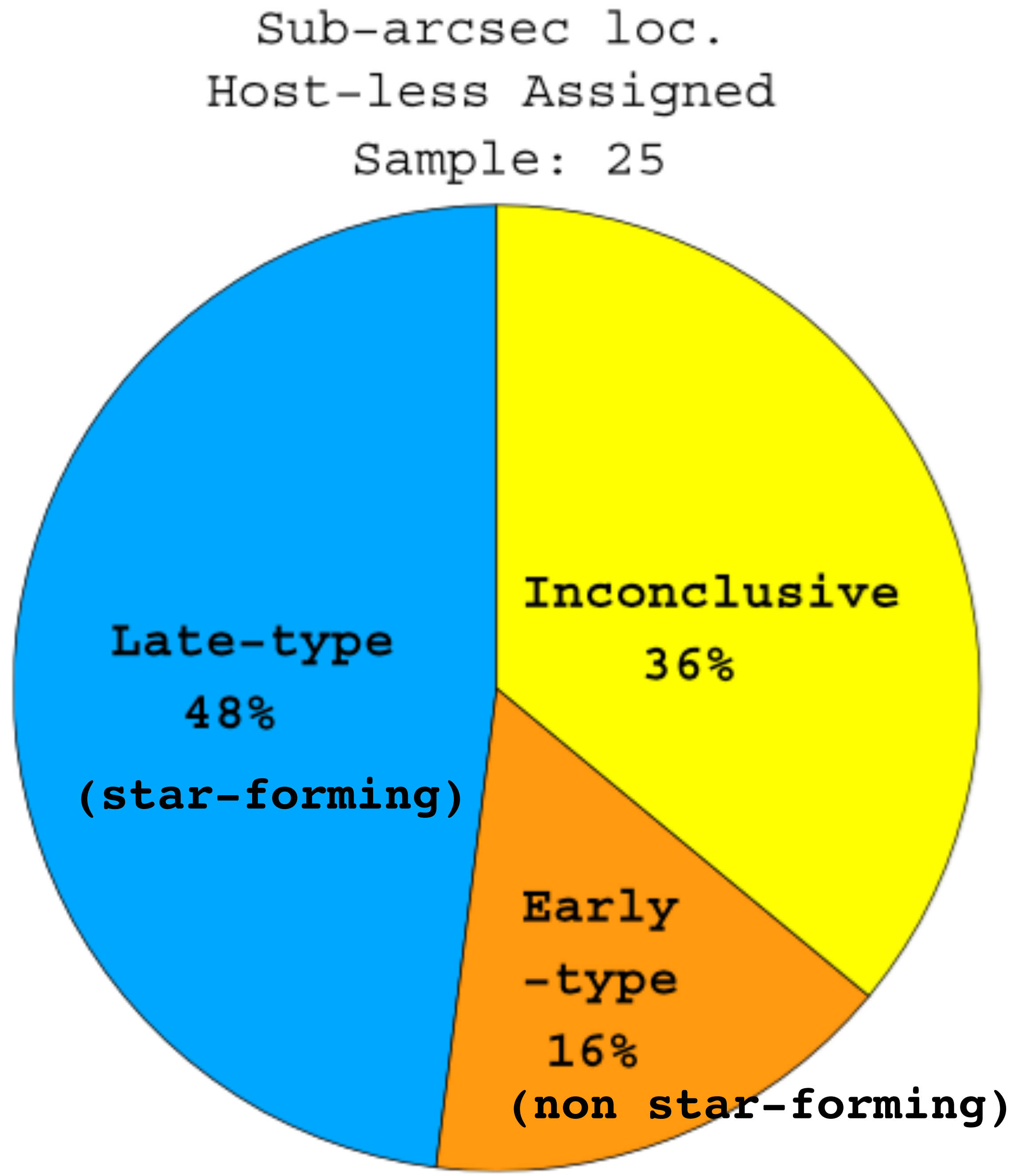



Beniamini et al., Astrophys. J., 832, 149 (2016) [plus annotations]

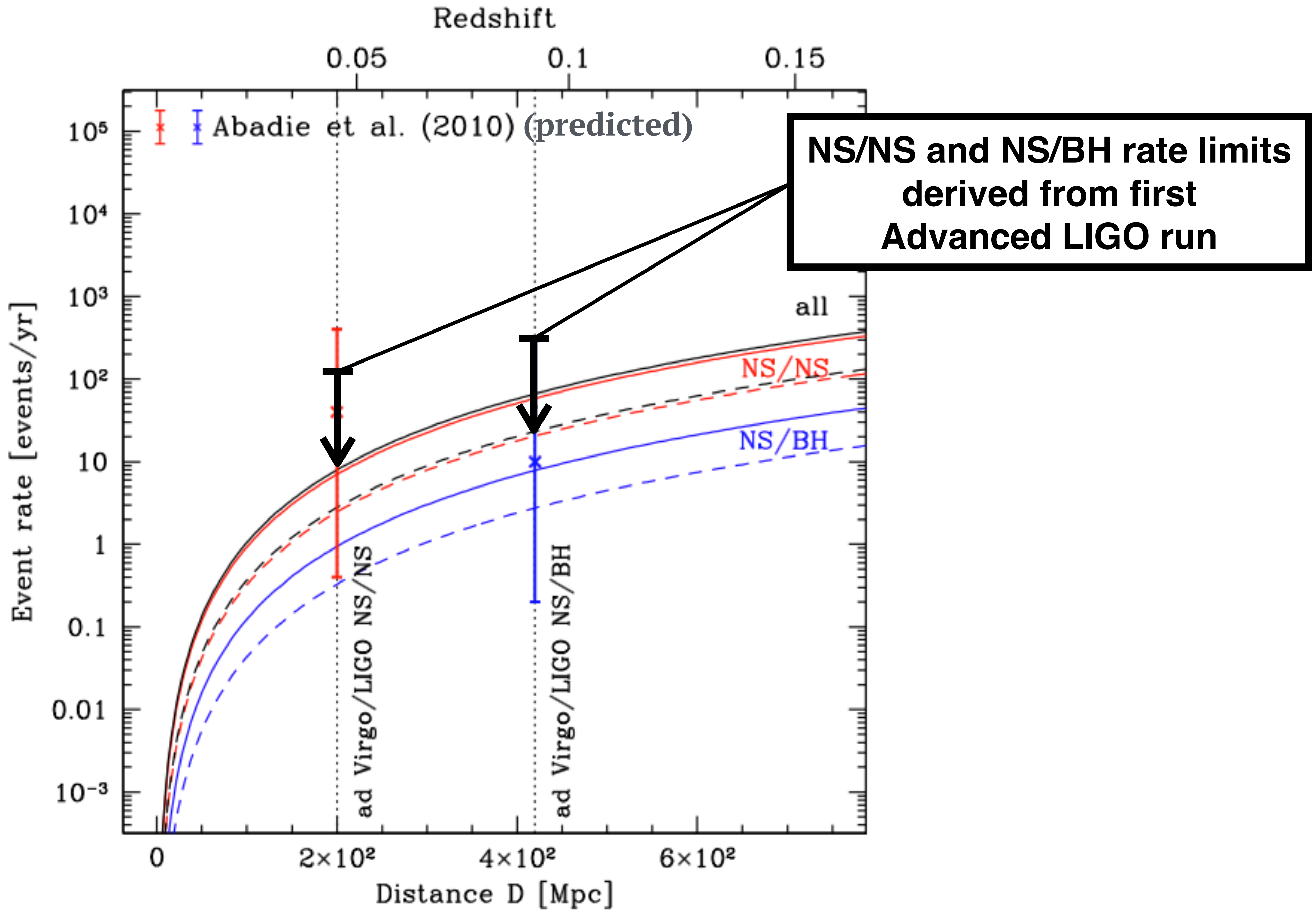



Beniamini et al., Astrophys. J., 832, 149 (2016) [plus annotations]

What are the host galaxies of short gamma-ray bursts (GRBs)?

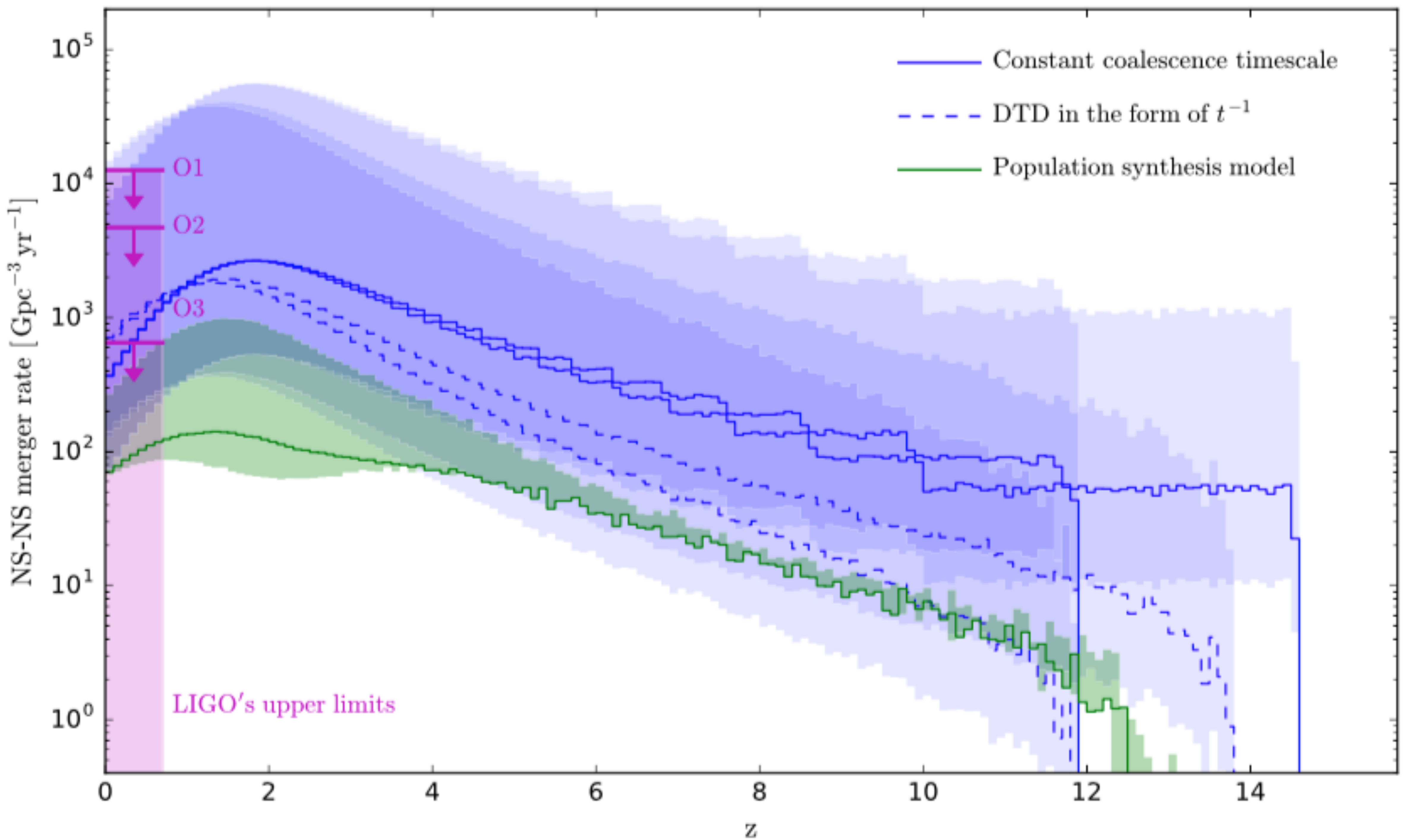



Fong et al., Astrophys. J., 769, 56 (2013) [plus annotations]



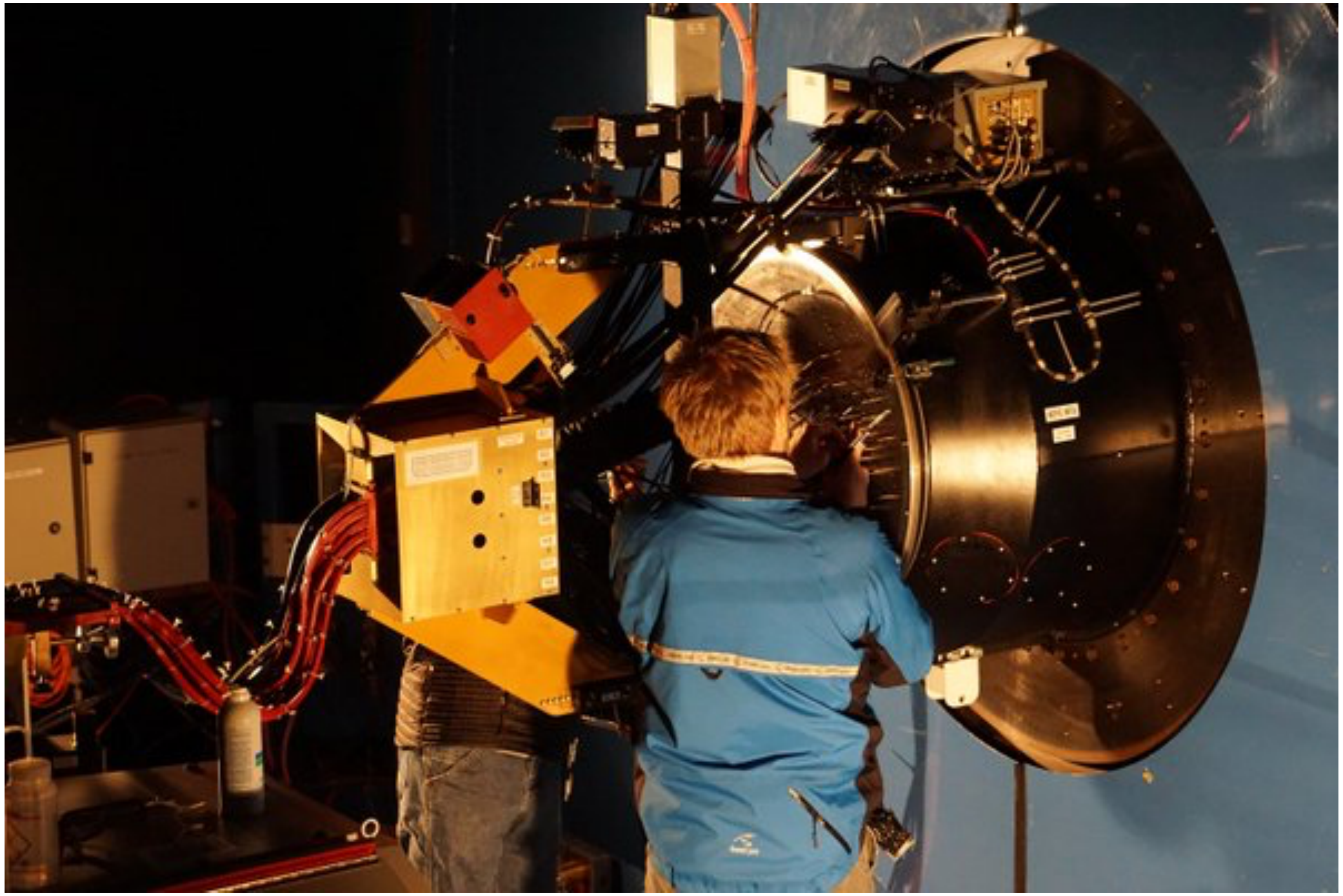

Vangioni et al., MNRAS, 455, 17 (2016) [plus annotations]

LIGO and Virgo Coll., ApJ. Let., 832, L21 (2016)




Côté et al., Astophys. J., 836, 230 (2017)

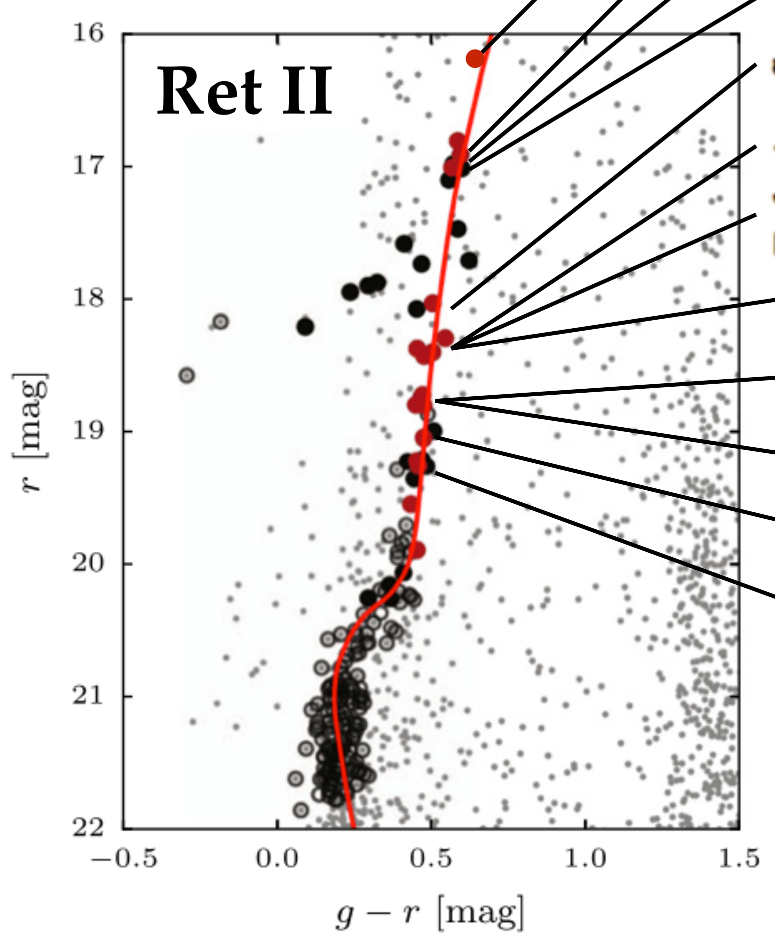
# The Michigan/Magellan Fiber System (M2FS) is well-suited for this followup.

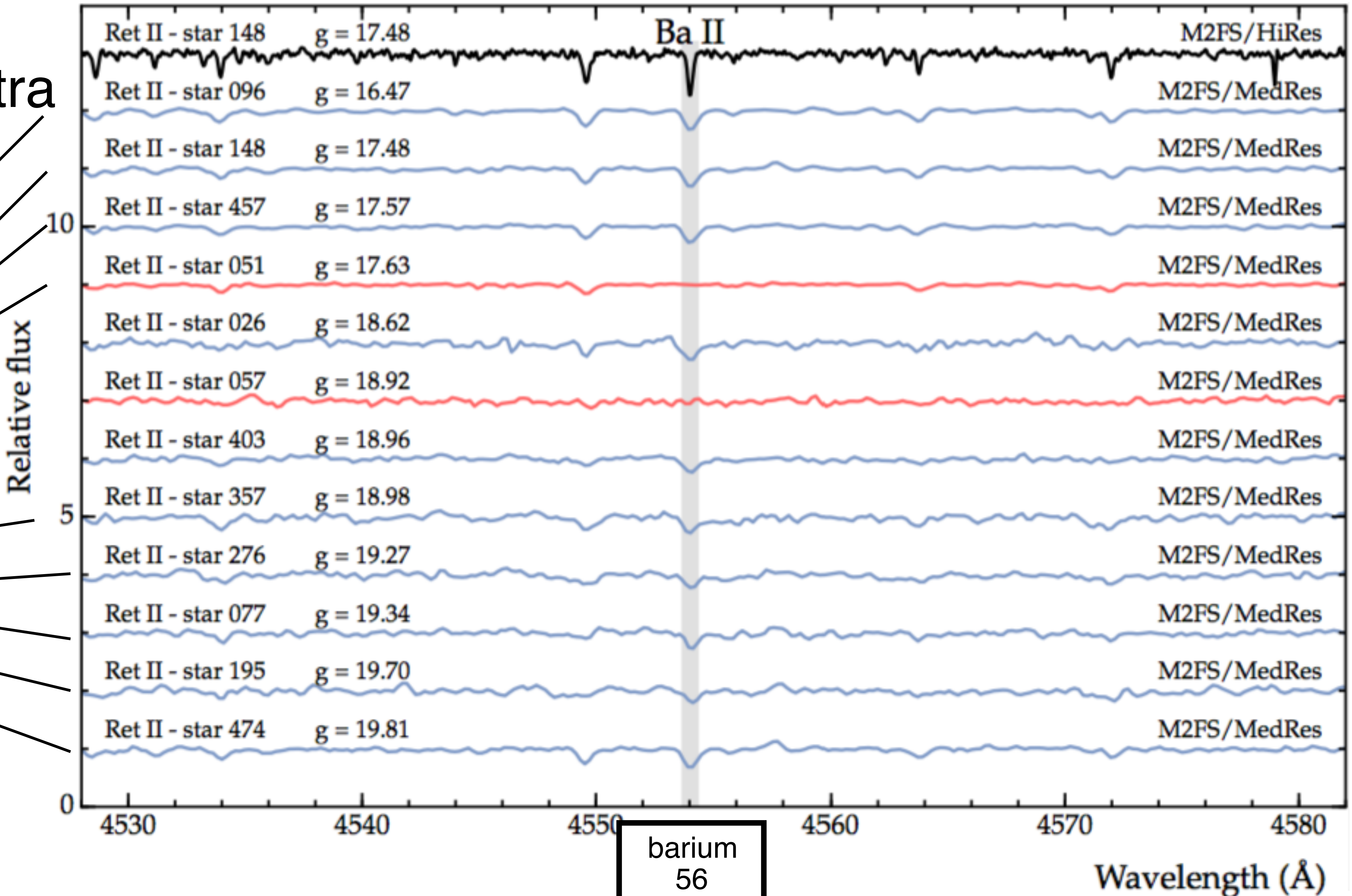


— versatile high/moderate/medium/low-resolution modes
— wide-field (30’ diameter)
— multi-object (up to 256 targets)

photo: C. Hull (Carnegie Obs.) and J. Bailey (Leiden)

# **Proof of concept:**
M2FS/MedRes spectra




barium
56
**Ba**
137.327

Data collected in 6.7 hours with M2FS/MedRes (R~8,000)

Roederer et al., in prep.

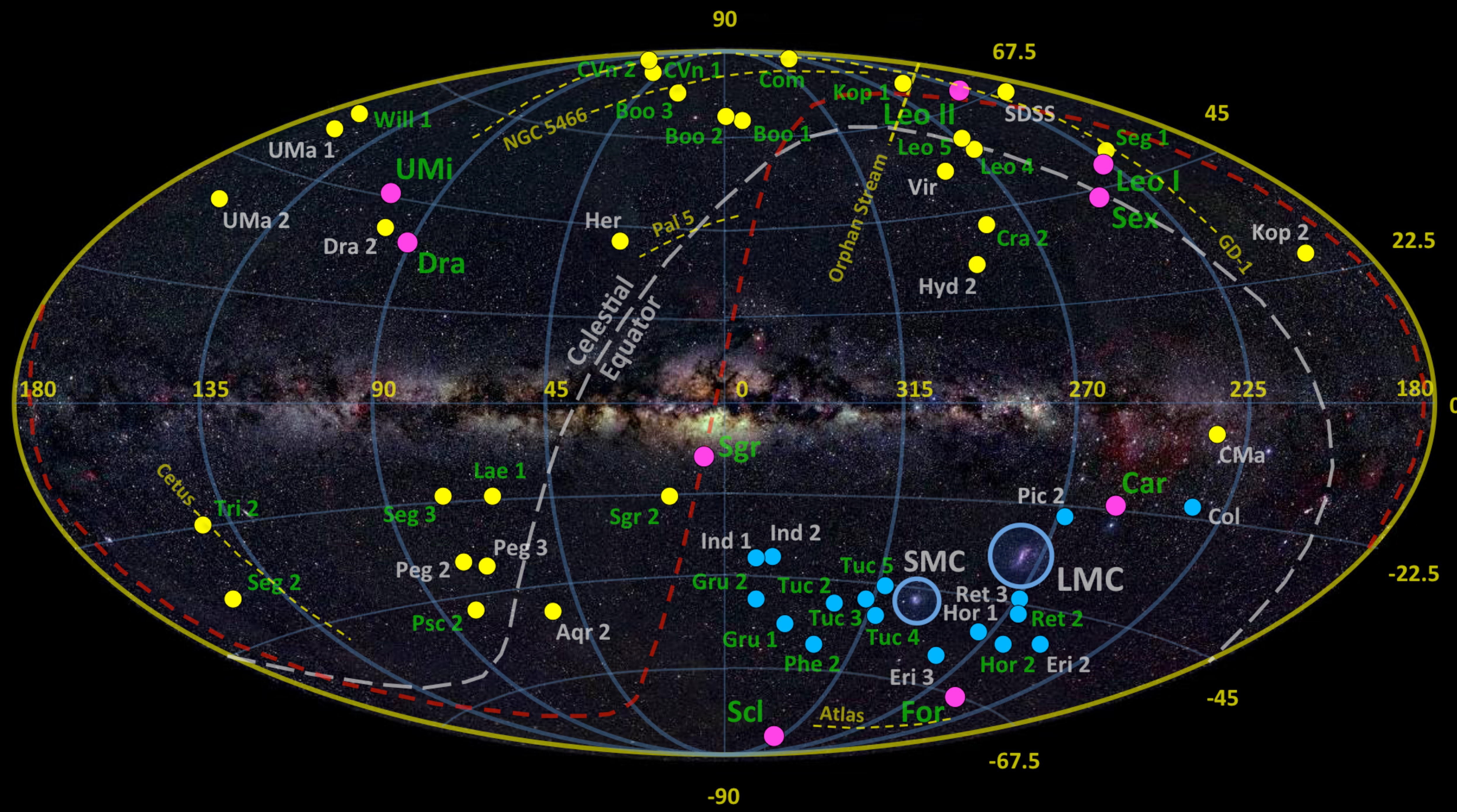



image: A. Mellinger (Central Michigan U.), M. Mateo (U. Michigan)

# Multi-object optical spectrographs accessible to astronomers at U.S. institutions

| Telescope (> 3m) | Multi-object spectrograph | Hemisphere N | Hemisphere S | Spectral resol. low | med | mod | high | U.S. public access percentage (~2017) |
|---|---|---|---|---|---|---|---|---|
| LBT (2 x 8m) | MODS | ✓ | | ✓ | ✓ | | | 4%* |
| Keck II (10m) | DEIMOS | ✓ | | ✓ | ✓ | | | 17%** |
| SALT (9.2m) | RSS | | ✓ | ✓ | ✓ | | | 0% |
| Gemini-North (8m) | GMOS | ✓ | | ✓ | ✓ | | | 29% |
| Gemini-South (8m) | GMOS | | ✓ | ✓ | ✓ | | | 33% |
| MMT (6.5m) | Hectochelle | ✓ | | | | | ✓ | 0% |
| | Hectospec | ✓ | | ✓ | ✓ | | | |
| Magellan II (6.5m) | M2FS | | ✓ | ✓ | ✓ | ✓ | ✓ | 0% |
| SOAR (4.2m) | Goodman | | ✓ | ✓ | ✓ | ✓ | | 30% |
| CTIO Blanco (4m) | COSMOS | | ✓ | ✓ | ✓ | | | 39% |
| AAT (3.9m) | 2dF+HERMES | | ✓ | | | | ✓ | 3%* |
| | 2dF+AAOmega | | ✓ | ✓ | ✓ | ✓ | | |
| WIYN (3.5m) | Hydra | ✓ | | ✓ | ✓ | ✓ | | 40%*** |

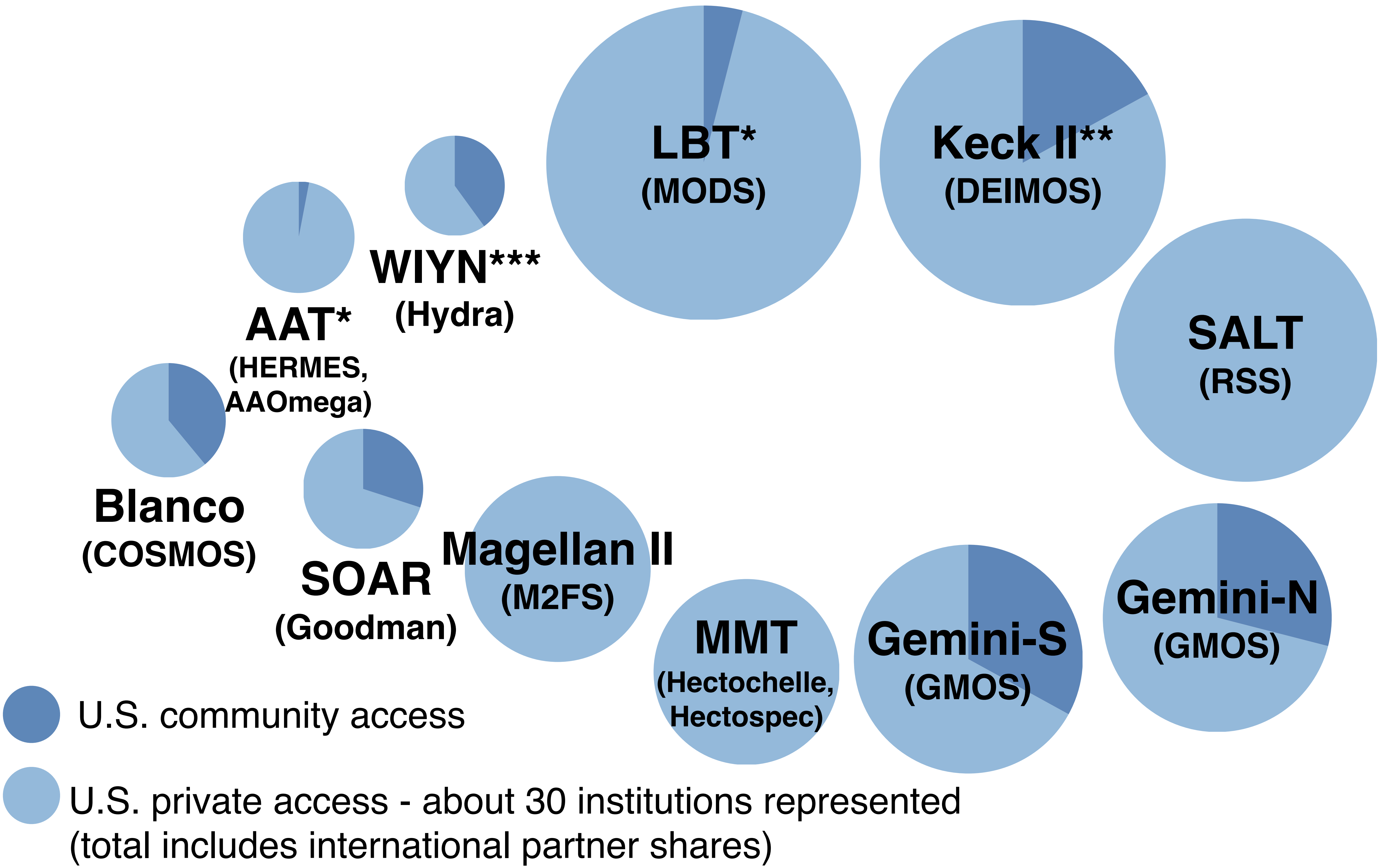
low: $R \lesssim 1{,}000$; med: $R \lesssim 8{,}000$; mod: $R \lesssim 20{,}000$; high: $R \gtrsim 20{,}000$

Needed for this followup (especially in the LSST era):
— large aperture (> 6 m) and
— moderate spectral resolution (R > 8,000)

* via TSIP
** for programs that support NASA missions and/or strategic goals
*** research related to exoplanets has first priority

**Multi-object optical spectrographs accessible to astronomers at U.S. institutions**

(on telescopes with > 3m primary mirror)

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| Keck II (10m) | DEIMOS | ✓ | | ✓ | ✓ | | | 17%** |
| SALT (9.2m) | RSS | | ✓ | ✓ | ✓ | | | 0% |
| Gemini-North (8m) | GMOS | ✓ | | ✓ | ✓ | | | 29% |
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| MMT (6.5m) | Hectochelle | ✓ | | | | | ✓ | 0% |
| | Hectospec | ✓ | | ✓ | ✓ | | | |
| Magellan II (6.5m) | M2FS | | ✓ | ✓ | ✓ | ✓ | ✓ | 0% |
| SOAR (4.2m) | Goodman | | ✓ | ✓ | ✓ | ✓ | | 30% |
| CTIO Blanco (4m) | COSMOS | | ✓ | ✓ | ✓ | | | 39% |
| AAT (3.9m) | 2dF+HERMES | | ✓ | | | | ✓ | 3%* |
| | 2dF+AAOmega | | ✓ | ✓ | ✓ | ✓ | | |
| WIYN (3.5m) | Hydra | ✓ | | ✓ | ✓ | ✓ | | 40%*** |

low: $R \lesssim 1{,}000$; med: $R \lesssim 8{,}000$; mod: $R \lesssim 20{,}000$; high: $R \gtrsim 20{,}000$

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| Telescope (> 3m) | Multi-object spectrograph | Hemisphere | | Spectral resol. | | | | U.S. public access percentage (~2017) |
|---|---|---|---|---|---|---|---|---|
| | | N | S | low | med | mod | high | |
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| SALT (9.2m) | | | | | | | | 0% |
| Gemini-North | | | | | | | | 29% |
| Gemini-So | | | | | | | | % |
| MMT ( | | | | | | | | % |
| Magellan II ( | | | | | | | | 0% |
| SOAR (4.2m) | | | | | | | | 30% |
| CTIO Blanco (4m) | CO | | | | | | | 39% |
| AAT (3.9m) | 2dF+HERMES<br>2dF+AAOmega | | ✓ | ✓ | ✓ | ✓ | ✓ | 3%* |
| WIYN (3.5m) | Hydra | ✓ | | ✓ | ✓ | ✓ | | 40%*** |

R ≲ 1,000 R ≲ 8,000 R ≲ 20,000 R ≳ 20,000

**There are no moderate or high resolution spectrographs on large-aperture telescopes accessible to astronomers at U.S. institutions.**

Needed for this followup (especially in the LSST era):
— large aperture (> 6 m) and
— moderate spectral resolution (R > 8,000)

* via TSIP
** for programs that support NASA missions and/or strategic goals
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# The environment of the r-process

**Ian U. Roederer**

**University of Michigan**

**and JINA-CEE**

Generous funding for my work has been provided by:

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WHERE DISCOVERIES BEGIN

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